RADIO-FREQUENCY-BASED GLOW-DISCHARGE EXTRACTION OF OXYGEN FROM MARTIANATMOSPHERE: EXPERIMENTAL RESULTS AND SYSTEM VALIDATION STRATEGIES. L. Vuskovic, Z. Shi, R. L. Ash, S. Popovic, and T. Dinh, Physics Department, Old Dominion University, Norfolk Virginia 23529, USA.

Abstract: Extraction of oxygen from Mars atmosphere was identified very early as a near-term opportunity for in situ resource utilization (ISRU) which could enable round-trip missions to Mars using existing space launch capabilities [1]. Since 1979, stabilized zirconia electrochemical cells have been studied as elements of oxygen production systems that operate using thermal dissociation of CO_2 (which constitutes 95.32% of the Mars surface atmosphere [2]) while separating and compressing the resulting oxygen product. Research at the University of Arizona has demonstrated long lifetime operation of the stabilized zirconia cells when operated at elevated temperatures and at terrestrial pressures [3].

On the other hand, the interface between Mars atmosphere and the zirconia cells has not yet been fully defined. Mars surface barometric pressure is nominally 6.6 mb (5 torr), but varies significantly due to the seasonal migration of carbon dioxide between the poles [4]. In addition, significant dust storms have been observed which occur at regular intervals [5]. Unfortunately, the instruments on board the Viking Lander spacecraft were unable to determine the composition of Mars dust and to date it has only been possible to infer its composition from terrestrial measurements [6]. It is desirable to filter the dust from Mars atmospheric feedstock, but because of the very low surface pressures, a generic filtration system must be designed which removes micron size particles without producing large pressure losses across the filter system [7]. To date, experiments have shown that the stabilized zirconia electrochemical cells are able to extract oxygen efficiently from pressurized Mars atmosphere, but the process of collecting and compressing Mars atmosphere prior to electrochemical separation represents a possible technology limit. In order to bypass that potential technology barrier, researchers at Old Dominion University and NASA Langley Research Center started to explore systems that could eliminate the need for filtration and compression of Mars atmosphere by uncoupling the oxygen production process from the electrochemical pumping process. Building from Outlaw's research on atomic oxygen production systems [8], we were able to determine that glow-discharge systems could be used to liberate oxygen from Mars atmosphere and that the oxygen could be collected through a silver permeation membrane [9]. Since the permeation membrane could be used as one electrode on a stabilized zirconia membrane, the resulting glow-discharge oxygen production system could either be separated from or integrated with the electrochemical cells.

The early experiments utilized direct current, glow-discharge techniques to increase oxygen yield from carbon dioxide at temperatures in the 300°C to 600°C range [10]. The objective was to show that it was possible to separate the oxygen production and collection processes from the oxygen compression process. Subsequently, stabilized zirconia cells could either be replaced by other types of vacuum pumping systems or they could be used as pumps, operating directly on the oxygen which passed through the silver permeation membrane/electrode. Hence, our research has shown that it was possible to extract oxygen from uncompressed Mars atmosphere at reduced temperatures, compared with the original zirconia-based designs. By utilizing a silver electrode/permeation membrane as the interface between the feedstock and the electrochemical cell, we were able to show experimentally that a glow-discharge could be sustained in the Mars atmosphere which resulted in significantly higher oxygen yields at lower temperatures [11]. That approach can eliminate the requirements for Mars atmospheric filtration and compression prior to oxygen extraction. However, too much electrical power was consumed via the DC glow-discharge to justify near-term ISRU system development studies based upon that technology. Even though the DC glow-discharge experiments demonstrated that an order of magnitude increase in oxygen yield, with no additional power, could be achieved by simply reducing the thickness of the silver permeation membrane by an order of magnitude, further reductions in power consumption were required. Since the ultra-thin silver permeation membranes could be used as the electrode surfaces on the stabilized zirconia cells—eliminating fabrication problems associated with leaks in the silver membranes—our research demonstrated how the glow-discharge system and the zirconia systems could be completely complementary if the power requirements could be reduced further. The DC glow-discharge power consumption was still considered to be

approximately one order of magnitude higher than levels that would be acceptable for ISRU systems for Mars surface applications.

Recently, radio frequency (RF) glow-discharge systems have been identified and tested which have the potential to reduce the glow-discharge power consumption levels sufficiently to justify experimental evaluation for possible use as the front end of an optimized ISRU Mars oxygen production system [12]. The experiments which will be reported here represent the current status of RF-based glow-discharge production of oxygen from Martian atmosphere. The experiments have been performed using an 0.32 mm thick silver (Ag0.05Zr) permeation membrane over a porous substrate. The discharge has been maintained at temperatures in the 300°C to 600°C range, with RF frequencies between 10 MHZ and 100 MHZ. Power consumption levels between 0.1 W/cm^2 and 4.0 W/cm^2 were maintained and the RF glow-discharge was operated in the pressure range between 1 torr and 10 torr. Pure carbon dioxide has been used as the feedstock gas thus far, but a three species approximation of Mars atmosphere (95.7% CO_2, 2.7% N_2, and 1.6% Ar) has been obtained and we expect to report preliminary results from those experiments as well.

Several encouraging results have been obtained to date. First, the RF glow-discharge appears to be optimized at 5 torr, which corresponds with nominal Mars ambient pressure. In addition, the temperature at which oxygen yield appears to approach maximum levels is approximately 400°C. These characteristics, coupled with the determination that oxygen permeation rates scale with the thickness of the permeation membrane, means that an RF-glow discharge system can be designed which consumes electric power at reasonable levels. That approach represents an attractive alternative to filtration, compression and elevated temperature operation of the stabilized zirconia cells that have been studied as the Mars oxygen production system of choice. The RF-system is both compatible with the earlier zirconia systems and capable of interfacing with other types of evacuation/compression systems that could be used for the oxygen compression and storage steps.

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